Limits and targets for a regional sustainability assessment: an interdisciplinary exploration of the threshold concept

Katharina Helming
Marta Pérez-Soba
Paul Tabbush
(Editors)

Sustainability Impact Assessment of Land Use Changes

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Dr. Katharina Helming
Centre for Agricultural Landscape and Land Use Research (ZALF)
Eberswalderstr. 84, D-15374 Müncheberg,
Germany

E-Mail:
khelming@zalf.de

Dr. Marta Pérez-Soba
ALTERRA
Wageningen UR, Droevendaalsesteeg 3, 6708 PB Wageningen,
The Netherlands

E-Mail:
marta.perezsoba@wur.nl

Mr. Paul Tabbush
Forest Research, Alice Holt Lodge, Farnham Surrey, UK, GU10 4LH
United Kingdom

E-Mail:
paul.tabbush@forestry.gsi.gov.uk

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Limits and targets for a regional sustainability assessment: an interdisciplinary exploration of the threshold concept

Nathalie Bertrand[1], Laurence Jones[2], Berit Hasler[3], Luigi Omodei-Zorini[4], Sandrine Petit[5], Caterina Contini[4]

(1) Cemagref, Grenoble, France
(2) Center for Ecology and Hydrology (CEH), United Kingdom
(3) National Environmental Research Institute (NERI), University of Aarhus, Roskilde, Denmark
(4) University of Florence, Florence, Italy
(5) INRA-ENESAD-Université de Bourgogne, France

Abstract

Some encompassing terminology is required in order to accommodate different conceptual approaches in the three pillars of sustainability. So, this chapter provides a literature review exploring the threshold concept. In environmental research – especially in ecology – thresholds are often associated with limits which have certain system-inherent processes. In social and economic disciplines, if the notion of limit or critical limit is present, the concept of *targets* is often more appropriate which are linked to political objectives and social acceptability. The concept of threshold is accommodated within the general framework of limits and targets. What is important is the understanding developed here that almost any environmental, social or economic system has the potential to reach a point or an area that is unsustainable, or outside acceptable limits, relevant at a regional level.

When identifying values for limits, a number of issues need to be considered. The consequences of exceedance of limits depend to a large extent on two related concepts, more or less relevant for both environmental and socio-economic sciences: path dependency and reversibility. Together, these help understand what the socio-economic and environmental consequences are, if they are reversible and the likely cost of achieving reversibility, or whether exceedance precludes any recovery. Exceedance of environmental limits often has a direct cost, revealed across many sectors, whereas the costs associated with exceedance of socio-economic limits may be harder to quantify. Together with a concept of risk, these concepts lead us to apply the precautionary principle, in other words to set conservative limits that define 'unacceptable consequences' some distance in advance of the point (or area) at which system break down or severe damage occurs. Crucially, these limits are derived through deliberative processes and involve both social acceptability and political input, together with scientific understanding of how the system operates (be it socio-economic or environmental).

Firstly, the paper explores the concepts of targets and limits from environmental and socio-economic perspectives and suggests some unifying terminology. Secondly, we examine some of the issues of uncertainty in considering values for limits or targets. These issues deal with the notion of equilibrium, the understanding of complex processes and the capacity of a system to adapt to an external event. Thirdly we underline how this uncertainty in the regional assessment challenges our ability to predict the consequences of exceeding the limits.

Keywords

threshold, target, limit, sustainability assessment, region, environment, socio-economy

1 Introduction: Defining a common objective for an interdisciplinary sustainability analysis

The rapid rate of land use change today has impacts on both environmental and socio-economic systems. Interdisciplinary research which is supposed to integrate these dimensions, encounters various issues including issues of spatial and temporal scale, and especially issues concerning common approaches to analysis. The integrated project SENSOR provides the opportunity for a regional sustainability assessment through the concept of regional thresholds. Indeed, the concept of threshold is used in SENSOR as a crucial component required to perform a regional sustainability impact assessment to support decision making on policies related to multifunctional land use in European regions. The challenge is to incorporate different social, economic and environmental ideas of thresholds and limits into one unified approach without compromising the underlying principles behind these concepts.

Several concepts of threshold arise from the processes studied, and notions such as equilibrium disturbance, breakpoint or area of change are commonly challenged for the three pillars of sustainability by: environmental, social and economic frameworks. In dealing with discontinuities in processes or change of regime (Matias et al., 2006), there are however differences in the way environmental and socio-economic sciences understand the concept. Through a literature review on theories involving thresholds in environmental and socio-economical studies, this chapter describes the ways boundaries of sustainability can be perceived in each discipline and how a synthesis of these ideas leads to the notions of limits and targets as a conceptual framework to set the boundaries of sustainability. The final objective of this chapter is to revisit the concept of threshold to provide the scope for the SENSOR regional sustainability assessment.

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2 An exploration of the concept of thresholds through limits and targets.

The idea of threshold has been recognised by ecology and ecological economists as a key concept to study changes in ecological processes and non-linear modelled economy-environment interactions (Muradian, 2001). However, definitions and understanding of the 'threshold' concept differ between environmental and socio-economic disciplines. In ecology, there is a large body of literature discussing thresholds, also called discontinuities, (reviewed in Folke et al., 2004; Huggett, 2005; Muradian, 2001; Scheffer et al., 2001), where the simplest definition of a threshold is: a rapid state change occurring as a consequence of smooth and continuous change in an independent variable (Luck, 2005; Muradian, 2001). Economic approaches based on the idea of equilibrium deal with discontinuities in the evolution of variables over time e.g. standard economic growth models or classical theory of localisation. In environmental economics, the concept can be related to an *optimum value* (e.g. cost/benefit to society) linked to social preference, pressure, market context or even policy decision, but also to the idea of substitutability between human and natural capital, which is discussed further below (footnote 1). In sociology, the term *threshold* is rarely used; although it does feature in some sociological models, like critical mass models.

2.1 Thresholds as discontinuities in processes

Thresholds or discontinuities refer to system change, linked to the notions of equilibrium disturbance, breakpoints or areas of rapid change in a system. In environmental systems, simple thresholds can be represented so that increasing pressure such as a pollutant load leads to exceedance of a threshold (Figure 1a at point A), beyond which point there is a drastic increase in damage, e.g. a loss of biodiversity. A thorough example of a lower limit threshold shown to operate in landscape ecology is detailed in Radford et al. (2005) who detected a limit of 10 % woodland cover required for woodland birds in a fragmented landscape in southern Australia. Below this level of woodland cover, species richness declined dramatically, while above this level, there was little change in species richness. Such empirical observations can be tested in modelling studies, e.g. modelling of fragmentation thresholds was reviewed by Andren (1994) who suggests that fragmentation thresholds typically occur where 10 – 30 % of suitable habitat remains.

The threshold concept has attracted much interest in ecological systems in the catastrophic switching between alternative stable states. These switches can arise in natural systems where a given set of conditions can result in multiple alternative states, as shown in population ecology models of predator-prey abundance (May, 1977). The catastrophic shift between stable states is illustrated schematically in Figure 1b. Up until point A_1, an increase in the pressure results in a more or less linear response in the response variable. However, at point A_1, a sudden shift occurs to a new state, at A_2. One example from marine systems is the influence of sea otters on inter-tidal kelp beds. With an abundant sea otter population, there is high macrophyte productivity, high density of fish and harbour seals, and low invertebrate density. However, a decline in sea otters through hunting causes a shift to an alternative state in which the conditions are reversed (Estes and Palmisano, 1974). Here the limits can be interpreted as the point at which a desirable state shifts to an undesirable state or at which one state shifts to another.

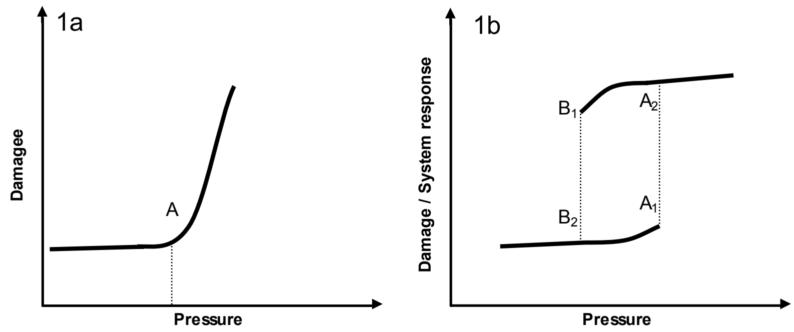

Fig. 1. Diagrams illustrating some general concepts of thresholds, relevant primarily to environmental systems, but also to some social and economic systems. 1a shows a simple threshold or breakpoint; 1b shows alternative stable states with the switch points occurring at system thresholds A_1 and B_1.

The idea of breakpoints or areas of rapid change is present also in economics in the context of equilibrium disturbance in the balance between benefits and costs in commercial exchanges. In spatial economics studies (i.e. Polèse and Shearmur, 2005) the concept was developed in relation to spatial concentrations of people. Also, in urban economics, through the question of cities' size and city expansion, the notion of threshold was used as an *optimum value* between human cost of urban concentration and benefits linked to agglomeration externalities for businesses (Catin, 1991; Paelink and Sallez, 1983; Parr, 2002). A similar concept has been used in the assessment of congestion effect of land use in agricultural activity (Bonnieux and Rainelli, 2000; Dupraz, 1996). In this case, the analysis of management practices and expenditure justification of agricultural production refers to thresholds as a point or area of change in which production of goods is substituted by an increase of positive/negative externalities (here congestion effect of land use). Threshold - as "critical" limit - expresses this relation of substitutability between environmental/rural amenities (positive externalities) supply and commodity outputs.

Finally, the use of threshold in a land use perspective can be strongly linked to ecological economic analysis, associating a value at which a good (or a service) provided to society changes or is considered to be maintained by society. However, the debate is open on the neoclassical utility theory which assumes that all values are commensurable and ultimately reducible to a single metric of economic welfare[1] (Malinvaud, 1972; Varian, 1992). Indeed, decision processes regarding choices on environmental issues are considered by other authors as non-compensatory, based on value hierarchies depending on ethics, behaviours, context, priorities between environmental and non-environmental goods and services. The notion of *lexicographic preferences* is used to express "a general unwillingness to trade or accept compensation for changes in an environmental good" (Spash, 2000). These preferences in environmental valuation overrule the assumption of continuously defined, differentiable preferences linked to standard neoclassical theory (Rosenberger et al., 2003). Two forms of lexicographic preferences are distinguished (Lockwood, 1996): a "strict" preference for which goods in any quantity or quality are always preferred over all quantities or qualities of other goods, and a more adaptable preference ("modified lexicographic preferences") based on thresholds (Lockwood, 1996). These thresholds correspond "*to minimum levels of a good that are necessary and prior to choice for other goods*" (Rosenberger et al., 2003)

2.2 Continuity in processes and non-threshold relationships: the notion of social and political targets

In reality, the exploration of non threshold relationships shows that most analyses of social and economic systems and also many relationships in ecology are not based on thresholds. The complexity of processes and re-

[1] Two extreme positions exist here however. The first ones are stronger positions (represented by Georgescu-Roegen, 1971) asserting that many natural ecological functions are irreplaceable and that any substitution is impossible. So, studies focused on ecosystem limits as a potential guide for management decisions, argue for stability in the ecological services provided by ecological systems (Muradian, 2001). In this case, economic threshold is defined as the period or a point at which the net income from cropping is reduced according to these ecosystem limits. Broader developments on thresholds are made in sustainability economics related to the idea of potential substitutability between man-made capital and natural capital (neoclassical positions represented by e.g. Solow (1992)) arguing that man-made capital can replace all natural capital, except for unique goods. Ayres (2006) argues that, while there is considerable scope for substitution in some domains, the limits to substitutability in the medium term at least are real and important. In this context, thresholds are so defined as at the point or area of substitutability.

gional dynamics, of links between drivers and "receptors"[2] make the definition of discontinuities difficult. This complexity in the analysis of processes is reinforced by the spatial scales and time dimensions involved.

Non-threshold relationships also apply in environmental systems. Simple linear relationships exist, for example an increase in the impervious area of a catchment through infrastructure development (soil-sealing) has been associated with an approximately linear decline in species diversity (Arnold and Gibbons, 1996). Relationships in ecology are based on complex links between living organisms and the physical and chemical conditions and processes within their environment. Therefore, the nature of the response being studied depends on both the scale at which it is studied and the range of the response gradient over which it is being assessed. Composite indicators, by their nature, are formed from the sum of the underlying responses, which frequently operate along the full range of the gradient. Thus, the resulting relationship may not exhibit a clear threshold. In a review of extinction thresholds for saproxylic (those dependent on dead wood) organisms, Ranius and Fahrig (2006) were able to tabulate proposed thresholds for a wide range of individual species studied, from woodpeckers to beetles, but could find no evidence of clear thresholds in studies analysing composite measures of species richness.

A broader overview of economic topics shows that most of the analyses are not based on thresholds, especially in the specific field of regional sustainable development. Far from a "simple" notion of growth, the complexity of development processes and regional dynamics involves different dimensions and different spatial and temporal scales. Regional analysis introduces a new scale of explanation for costs/benefits of a spatial localisation involving spatial division of work (Aydalot, 1984), rationale of decision processes and individual behaviours of localisation (Scott, 2001; Storper, 1997), and the importance of institutions in dynamic processes (Marshall, 1906; Becattini, 1992; Benko and Lipietz, 1992).

If limits are identified, scientifically based or not, they refer often more to social preferences and political objectives, which are better referred to as targets. Targets represent a desired endpoint on a relationship curve, whether that curve is linear or exhibits clear thresholds. Targets have been used in ecology, for example in relation to national Biodiversity Action Plans[3]. In the International Convention on Biological Diversity (CBD) a

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[2] Even if the term is less appropriate for social and economic analysis, these comments are relevant for all three approaches.

[3] For an example from the UK, see http://www.ukbap.org.uk/GenPageText.aspx?id=98

range of environmental targets has been defined[4] some of which are based on a numerically defined target (e.g. Target 1.1: At least 10% of each of the world's ecological regions effectively conserved), while others are based on improvement relative to a current position (e.g. Target 5.1: Rate of loss and degradation of natural habitats decreased). From the economic and social perspectives and concerning regional development at the European scale, targets are clearly identified in the European Union as: political goals and norms for a sustainable European development. These refer also to a specific vision (or model) of European polycentric spatial development (ESDP, 1999) to achieve two policy goals: making the EU economically more competitive in the global market (according to regional concurrence and attractiveness), more socially and spatially cohesive and equitable (Third Cohesion report, 2004; Lisbon Agenda, 2000 and Göteborg Agenda, 2001).

In both socio-economic systems and environmental systems, targets can be more complex with an optimum at a specific value, and sub-optimal conditions on either side. In the environment, such relationships expressing the full range of optimum and sub-optimum conditions are often represented as bell-shaped curves. For example, abundance curves for individual species along an environmental gradient which often follow a Gaussian distribution, or composite responses such as the species richness curve along a fertility gradient described by Grime (1973). In socio-economics, such policy targets exist for addressing social inequality, and are measured in units of deviation from the EU average level.

Thus, as is evident from the different conceptual approaches outlined above, a key challenge is how to accommodate these different conceptual frameworks into one workable system, ***limits*** based on established threshold relationships or breakpoints –or areas of sudden change which define the point beyond which unacceptable consequences are likely to occur, and ***targets*** referring to political objectives or social preferences, which define the aspirational goals towards which we strive in order to achieve sustainability.

3 Issues of uncertainty to consider when defining values for Limits and Targets

A main dimension of sustainability assessment is in identifying and deciding on values for limits and targets. Two main purposes are to assess how

[4] See http://www.biodiv.org/2010-target/goals-targets.shtml

their potential exceedance affects sustainable use of land and how limits' values can be used to set the boundaries for regional sustainability. The concept of a narrowly defined threshold is subject to uncertainty, giving rise to a "critical area". This is true in the life sciences and for some economic and social analyses (Steyer and Zimmermann, 1998).

Indeed, there is always some uncertainty in the underlying data used to define a process or a relationship. However, limits are usually developed on the processes that are best understood, using the most comprehensive data sets and information available. Therefore uncertainty at this level is less of a problem than later on in the process of using and applying limits, as long as the areas of uncertainty are recognised and documented. The main dimensions in the issue of uncertainty are outlined here, especially with regard to the level of understanding and knowledge that we have on any relationship or process.

What are the factors of uncertainty in determining an indicator value in terms of limit and target? Does this uncertainty jeopardise the assessment? The following topics relevant to the environment but also to economic and social indicators acknowledge some of the uncertainties and related issues (resilience, path dependency, reversibility, vulnerability) that need to be taken into account when defining the limit values to be used in the assessment.

3.1 Equilibria and indifference curve in economic limits valuation

A wide-ranging debate is open in economics on process equilibria (and thus on limit values). It opposes classical and neo-classical approaches for which a general stability is established in a context of perfect competitive market (based on rational behaviours and commercial exchanges); to heterodox approaches criticising, in complex systems, establishment of a single equilibrium. This general debate has however relevance to limits' value definition, especially for "critical limits". Two examples can be underlined here to illustrate this.

A set of studies and models concerns dynamics of growth among the poor and of self reinforcing patterns of chronic or persistent poverty (Barrett and Swallow, 2006). The standard economic growth model assumes implicitly that there is a single dynamic equilibrium and hence convergence of all growth paths toward a single level of welfare. If the curve lies above the dynamic equilibrium (limit) there is growth, if the curve lies below the dynamic equilibrium there is decline. However, the recent United Nations Millennium Project Task Force (UNMP, 2005) recommends another conceptualisation of persistent poverty based on the notion of "poverty traps" which depends on the existence of multiple dynamics of equilibria: „The evolution of well-being over time then depends on where one sits relative to the critical thresholds(s) at which the growth function bifurcates" (Barrett and Swallow, 2006, p.4). Another example is illustrative of the difficulty in defining a limit within equilibrium. From a neoclassical welfare economic point of view society can, according to „indifference curves“, have the same welfare or wellbeing level with different combinations of goods and services. Based on these considerations the same level of economic welfare can be produced by different combinations of marketed and non-marketed goods, and from an economic point of view, thresholds are therefore hard to find.

3.2 Understanding of complex processes, social acceptability

A degree of uncertainty often exists in our level of understanding of the relationship between the driver and the receptor, or the underlying processes. In environmental systems, it is common that the consequences of limit exceedance are much better understood than the mechanisms leading to limit exceedance, or the precise definition of where the limit lies (Huggett, 2005). In the case of the switch of a lake from turbid to clear conditions, some of the mechanisms which cause the switch and the impact on the lake ecology are well studied, but the precise value of the nutrient concentration at which the switch occurs is difficult to predict (Donabaum et al., 1999). Similar principles apply in socio-economics. The level of complexity and inter-connection between factors in a development process, or socio-economic use of land is so high that in most cases the identification of a value for an indicator limit is beset with uncertainty.

A good example is given in environmental economics referring to the evaluation of demand based on the aggregation of individual preferences. Uncertainty can arise as to social preferences, but also due to the wide range of methods available for evaluation of the willingness to pay to maintain (or have access to) the good or the service involved: e.g. hedonic pricing (Le Goffe, 2000), travel cost methods (Desaigues and Point, 1993); stated preference methods including contingent valuation (Amigues et al., 1996). While these valuation techniques reveal the preferences for individuals, the values obtained by other methods are based on the preferences of political bodies, experts and stakeholders, e.g. the DELPHI method

(Navrud and Pruckner, 1997); multi-criteria methods (Wenstop and Carlsen, 1988)[5].

3.3 Limits with respect to vulnerability and adaptive capacity of systems

In setting limits, we have to take into account the potential impact of its exceedance, and hence the vulnerability (or sensitivity) *vs.* resilience of the system studied. This can be seen as an adaptive capacity and a degree to which a dynamic process is susceptible to, or unable to cope with, adverse effects of pressures. An important property of limits is the vulnerability of the system studied and the idea of increasing risk as the Limit is approached.

As an example, a pressure to which vulnerability assessments are frequently applied is climate change, including climate variability and extreme weather phenomena. Thus, the IPCC Third Assessment Report (TAR) describes vulnerability as "*The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity*" (IPCC, 2001)[6]. Vulnerability is therefore an integrated measure of the potential to respond to change. As such, it incorporates features of environmental systems (ecosystem services), but they are integrated within the socio-economic context of a region or country over time.

In socio-economics, what is in balance is the ability of populations to cope with exposure to certain pressures. So, vulnerability has been specifically defined in the field of food security as "*an aggregate measure for a given population or region of the risk of exposure to food insecurity and the ability of the population to cope with the consequence of the insecurity*" (Downing, 1991). More generally, the socio-economic literature discusses the difficulty in achieving a clear understanding of vulnerability, because it is often identified with only one of its causes (Delor and Hubert,

[5] These types of economic valuation on environmental goods have been numerous during the last 20 years in Europe. The Data bases EVRI (Environmental Valuation Reference Inventory), ENVALUE and the Swedish valuation data base can be used to view a number of these studies.

[6] Definitions are also presented in this report for "Exposure": "The nature and degree to which a system is exposed to significant climatic variations" and "Sensitivity": "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli".

2000). In natural hazards science, three co-ordinates of vulnerability are underlined: the risk of being exposed to crisis situations (exposure), the risk of not having the necessary resources to cope with these situations (capacity), and the risk of being subjected to serious consequences as a result of the crises (potentiality). Finally, in the analysis of social cohesion, the complexity of socio-economic vulnerability is underlined (Sen, 1981; Moser, 1998), defining informal settlements according to 4 elements: degree of marginalisation, absence of opportunities for asset retention and growth, local perception of poverty, compromised use of space related to the access by emergency and service vehicles.

4 Challenges of applying threshold concepts at a regional level

The sections above have underlined the dimensions of uncertainty, relevance and robustness of an assessment. When it comes to the practical issue of applying these principles to a regional assessment, some further issues arise. There are likely to be differences in the values ascribed to limits, both within regions but particularly between regions. These arise for example from differential local values attached to economic growth *versus* environmental protection.

With interpretation of any type of limit, there are likely to be strong differences in the values ascribed to limits, both within regions but particularly between regions. To present some broad generalisations as examples, a wealthy, heavily urbanised or industrialised region is likely to place a high unit value on an environmental resource (e.g. nature reserve, bird species) than a predominantly rural region where that resource is plentiful and where there are other social priorities such as a high level of unemployment; but contradictory cases can be found for example in urbanised areas with severe problems of unemployment and priorities given to economic activities. These differences are not always clear-cut. For example, both an urbanised and a rural region may both strongly value areas of woodland but for different reasons. The former may see it as having amenity value in tourism and recreation, the latter may value it as a livelihood for local companies extracting timber. Thus, these differences in the value attached to limits may strongly influence the marginal costs and gains associated with a change in indicator value, relative to a limit.

4.1 Sensitivity of an indicator to reflect processes of change

If many different interpretations of the term ‘sensitivity’ are developed, the sensitivity of an indicator challenges its capacity to reflect processes of changes or relationship to factors outside the basic system which it describes.

In the environment, the sensitivity of an indicator/relationship may operate at different levels, and be governed by factors such as internal characteristics which differ on a regional basis. For example, management regimes in European grasslands can alter their sensitivity to eutrophication (in terms of species change) (Achermann and Bobbink, 2003) due to local variations in how grazing or hay cutting are carried out. An indicator may also be sensitive to external forces. For example, are relationships governing the level of methane emission from land-use types equally valid under different climate change scenarios? Moreover, the form or the realised extent of a relationship may differ regionally across Europe. For example, a farmland birds indicator is composed of abundance of a number of different species whose ranges differ across Europe. Therefore calculation of such an indicator will draw on different species and populations in each region for which it is calculated, with the potential for differing sensitivity to land use change.

These issues of data relevance are also present in socio-economic arenas (particularly where national average data is disaggregated and used to identify regional limits for indicators) and issues of indicator sensitivity (in terms of representativeness of the change and side-effects of this change). A number of factors influence the assessment robustness. One of them is the indicator sensitivity in regional assessment and the selection of indicators in terms of indicator adequateness – according to the processes targeted and the spatial scale considered - and data availability. Description of complex processes often demands composite indicators subject to some uncertainty (weighting, availability of data etc.). The GDP indicator gives a good example of this uncertainty. GDP is often one of the main parameters (with employment rate, rate of inflation, …) selected from the 70s to measure growth as an indicator of economic success (Gadrey and Jany-Catrice, 2005), but it is subject to increasing criticism, coming sometimes from economists but more often from other disciplines: sociologists (economic growth is not necessarily a measure of social well-being) or natural scientists (economic growth is often accompanied by environmental destruction). The GDP indicator refers mainly to growth and does not consider all dimensions of development (sustainable or not) especially an indicator of human progress or welfare[7], that will limit the scope of the assessment at regional level. Moreover, some European objectives are political targets leading to questions on the sensitivity of available indicators at pan European level (at Nuts X scale[8]), and potential hidden side-effects. Main objectives of a competitive, equal, sustainable and cooperative European union are underlined in European documents. These concepts are quite complex and there is little chance of finding indicators that can cover all aspects, and very few relevant indicators have yet been developed.

The sensitivity of an indicator may vary at different spatial scales, or may differ geographically depending on local conditions. For example, patterns of connectivity within a landscape unit are relevant at a range of scales from tens of metres to hundreds of kilometres depending on the mobility and territory size of species, but also in the long term for providing avenues for range extension or adaptation under conditions of climate change. Sensitivity of a socio-economic indicator has also to be questioned according to the spatial scale. If indicators, on the basis of socio-economic data, are available only at the national level, their effectiveness or even meaningfulness at a lower level can be highly questionable. Sensitivity of an indicator may vary at different spatial scales.

4.2 Ability of a system to recover from stress and consequence of change

An important aspect in understanding sustainability is the way an environmental or socio-economic system recovers from stress, and what are the consequences when a limit is passed.

It is recognised that the factors which tip an environmental system over a limit may be relatively minor or chance events, and that the key issue is the resilience of the system to deal with these, i.e. resilience is the ability to absorb perturbations and still persist (Holling, 1973, 1986). One example based on habitat fragmentation thresholds for woodland bird diversity illustrates this property. In a highly connected habitat, stochastic events

[7] A. Sen (1996) has also challenged GDP as a meaningful indicator and has inspired in the United Nations Development Programme the Human development index to monitor the state of human development in the world. This index is calculated by averaging the indicators related to the 3 following aspects: Life expectancy at birth; education (measured by adult literacy and educational enrolment rates) and GDP per capita.

[8] NUTS X regions are the spatial level at which the majority of the indicator calculations are processed in the SENSOR project. They are an amalgamation of the NUTS 2 and NUTS 3 administrative units of the EU.

such as storms or fires which cause a small or temporary decrease in available habitat are not likely to affect the bird population size. However, as the habitat thresholds are approached and resilience (habitat connectivity in this case) decreases, stochastic events which are relatively small in magnitude have the potential to over-reach the limit, with severe consequences for the bird population.

In the same direction, extensive socio-economic work has been done on causes and impacts of livelihood shocks (Sen, 1981; Davies, 1993; Devereux, 1993; Putman, 1993). This has inspired a large number of urban studies of household responses to economic crisis, studying the ability to recover from a stress, and of structural poverty reduction strategies focussing on assets of population (Moser, 1998). Especially, urban studies have questioned the ability of the population to cope with the consequences of the insecurity (Downing, 1991), from the sensitivity of a population to its responsiveness. C.O.N. Moser (1998), categorised the assets of poor urban individuals including: tangible assets (labour, human), productive assets (housing) and intangible assets (household's composition and structure, cohesion of family members, mechanism for pooling income and sharing consumption, social capital –reciprocity within communities and between households). In addition, recent conceptual debates and policy recommendations – deriving from rural famine, food security research, have introduced also in the social and development debate concepts of vulnerability or sensitivity.

Another property of some indicators that has to be taken into account is "path dependency", where the sequence of events over time determines the end point or character of the system, In socio-economics, "path dependency" is defined as where the development process is embedded depending on its past history, on the entire sequence of decisions made by agents and resulting outcomes, and not just on contemporary conditions. In these local dynamics each step of a new equilibrium depends on the path already taken from the initial situation. Similar considerations apply in the field of technological research, showing also how technological regimes are channelled – (path dependent) in a 'technological paradigm' (Dosi, 1988).

The concept applies also for environmental systems where the sequence of events over time determines the end point or character of the system, rather than a combination of factors resulting in a guaranteed endpoint once a set of ecological requirements have been met. For example, vegetation assemblages could be seen as path dependent, where the composition of a plant community depends on migration rates of different species as the climate changes, and on evolutionary change and stochastic factors governing success or otherwise of particular species. A related concept is hysteresis, which shows that reversing a set of conditions does not always reverse the consequences at the same time or in the same way; in other words the relationship may change. This is illustrated in Figure 1b above where the shift in an environmental system from state A to state B occurs at one level of environmental pressure but when conditions are reversed, the switch back to state A occurs at a different point. For example, with respect to soil acidification, once soil pH has dropped below a certain level, even if anthropogenic inputs of acidifying compounds are drastically reduced, the time taken for natural replacement of base cations in the soil profile depends on the rates of mineralisation of parent rock and can take decades, or even centuries (Reynolds, 1997). This has strong implications for the reversibility of limit exceedance.

Therefore, a key issue in the assessment is how important limit exceedance is, and whether the former condition can be regained (reversibility). In some cases, once a limit is exceeded, this is an absolute position, which can not realistically be returned from. For example, following expansion of urban residential area into formerly agricultural land use, it is highly unlikely, or extremely costly, to reverse that change. Recovery from some situations is technically possible but due to cost, timescale, political or social considerations it becomes effectively impossible. Other changes may allow full or partial recovery, for example land abandonment due to rural depopulation, or reducing pollutant inputs to the environment and in these cases reversibility should be aimed for. In essence, these factors of path dependence and reversibility help inform the consequences of limit exceedance, in that they have cost and timescale implications which must be taken into consideration when defining values for limits.

5 Conclusion: Identifying regional values for limits and sustainability boundaries

Does it matter if the system switches? Is the change, to all practical purposes, absolute, or to what degree can it be reversed? What are the cost and resource implications? The way to answer these sorts of questions may be quite different between environmental sciences and socio-economic sciences. However, both raise the question of how these can be adequately analysed, interpreted and managed.

When identifying values for limits, a number of issues need to be considered. They take into consideration the socio-economic and environmental consequences of the exceedance of limits to a large extent linked to the reversibility of a system (the likely cost of achieving reversibility) and to its dependence on past history (concept of “path dependency”), on the entire sequence of decisions made by agents and resulting outcomes, and not just on contemporary conditions. In a more obvious way, path dependency is apparent in regional development assessed within SENSOR. In these local dynamics each step of a new equilibrium frequently depends on the path already taken from the initial situation. Therefore, the purpose is not to define a limit before or above which the regional dynamics change, but to understand irreversible phenomena which define for each region possible future paths.

Together with a concept of risk, often illustrated within the growing field of vulnerability assessments, acknowledgement of all these concepts leads us to apply a *precautionary principle,* in other words to set conservative limits that define ‘unacceptable consequences’ some distance in advance of the point (or area) at which system break down or severe damage occurs. Crucially, this setting of limits demands consensus and involves both social acceptability and political input, together with scientific understanding of how the system operates (be it socio-economic or environmental). In environmental systems risk is indeed usually related to limits, beyond which we see unacceptable consequences and the desire is to remain as far from that limit as possible. In social and economic systems the social dimension of risk is emphasised. UNESCO underlines its double dimension: risk is a crossing product between hazard – probability of occurrence of an event with certain intensity (avalanches, river flood…) - and vulnerability – exposure to socio-economic issues linked to this hazard (goods, human beings, activities …).

Taking into account these issues is necessary to identify the boundaries of sustainability. These are often considered in vulnerability assessments either explicitly or implicitly. Together, they define the social, economic and environmental costs which determine the effective consequences of limit exceedance, and therefore the political weight to be attached to avoiding that exceedance.

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